Modeling and Simulation of Switched Reluctance Motor with Three-Phase and Four-Phase Configurations

Abdolamir Nekoubin

***Abstract*—**The reluctance motor is an electric motor in which torque is produced by the tendency of its moveable part to move to a position where the inductance of the excited winding is maximized. In this paper switched reluctance motors (SRMs) with two different configurations(3-phase SRM with 4rotor poles and 6 stator poles, 4-phase SRM with 6rotor poles and 8 stator poles) is designed by RMxprt, and performance of them is analyzed. Efficiency and torque of SRM for different configurations in full-load condition have been presented. The results indicate that with correct choosing of motor applications, maximum efficiency can be found.

***Keywords*—** reluctance motor, maximum efficiency, rotor

I. Introduction

THE reluctance motor is a type of synchronous machine. It has wound field coils of a DC motor for its stator windings and has no coils or magnets on its rotor. In this motor both the stator and rotor have salient poles; hence, the machine is a doubly salient machine. The rotor is aligned whenever the diametrically opposite stator poles are excited [1]. In a magnetic circuit, the rotating part prefers to come to the minimum reluctance position at the instance of excitation. While two rotor poles are aligned to the two stator poles, another set of rotor poles is out of alignment with respect to a different set of stator poles. Then, this set of stator poles is excited to bring the rotor poles into alignment [2].The switched reluctance motor turns many of the tenets of classical electric machines technology upside down. This possibly explains why it is popular with academics but rare in the factory. Since the emergence of serious examples of switched reluctance drives in the 1970s, only a few practitioners have made successful businesses with them, while a large number of research papers have had little effect at the factory gates and some of them make claims which are misleading or incorrect [3-4].The enormous investment in tooling and infrastructure for induction motors and ac drives puts the switched reluctance motor at a disadvantage in many large sectors of the motor business. Since the vast majority of induction motors are line-start motors used without electronic drives, the switched reluctance motor has no hope of competing with the induction motor in the bulk of these applications. The infrastructure relates to the design, manufacture, sale, commissioning, maintenance, and control, and in adjustable-speed drives all these are heavily weighted in favor of induction motors. By contrast, the switched reluctance motor and its drive are specials for which very little tooling exists and almost none of the infrastructure [5-6-7]. This will limit its role to special applications where the costs of development and support can be absorbed in a larger project for example, the development of a completely new washing machine [8]. Although the switched reluctance motor appears beguilingly simple, it requires a small air gap and better concentricity than an induction motor. To achieve comparable efficiency and power density at full load, it may require more copper and/or a higher winding temperature [9].For acceptable performance, it requires an accurate shaft position feedback signal, implying the need for a "servo-quality" encoder or resolver or, alternatively, a sophisticated sensorless controller that will, in general, be specific to one application [10].The switched reluctance motor has no independent means of excitation. In this respect, it differs from all permanent-magnet machines and from dc or ac machines with separate field windings, such as the classical synchronous machine. The excitation in the switched reluctance machine is in the voltamperes supplied by the drive [11].It can be regarded as a component or fraction of these voltamperes, the remainder being accounted for by real power, which divides between the useful output and the losses. In this respect, the switched reluctance motor is similar to the induction motor [12]. The fraction of the supplied volt-amperes which is converted to useful output power is similar to that of the induction motor and, therefore, it cannot be said that switched reluctance motors have a problem with excitation, any more than induction motors do [13-14]. In this paper switched reluctance motors with two different configurations is designed by RMxprt, and performance of them is analyzed.

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II. Motor Characteristics

This motor type operates with shaft position feedback to synchronize the commutation of the phase currents with precise rotor position. Typically, both the stator and the rotor are salient to increase the torque-producing characteristics of the motor. The rotor has no windings; the torque is produced by the alignment tendency of the rotor to the stator so that the stator flux linkage is maximized. In these motors, the stator and rotor have different numbers of poles. The stator phase windings are energized at precise moments synchronized with the position of the rotor. The task of energizing the stator windings is performed by a complex electronic system. The number of phases in the winding is the ratio of the stator number of poles to the smallest common divider of the stator and the rotor number of poles. In switched reluctance motors (SRM), the stator and the rotor have a different number of poles, and the stator currents are commutated exactly according to rotor position. The signal of the rotor position is obtained from a position sensor. The stator windings are triggered one by one, and normally the current in a winding has finished or almost finished freewheeling when the next winding is triggered. Therefore, the mutual effects between two phases can be neglected. The efficiency of the electric machine is computed by:

$$eff = Pin / Pout \quad (1)$$

$$Pout = Pin - (Pfw - Pcu - Pt - Pfe) \quad (2)$$

III. Switched Reluctance Motor Design

In this section switched reluctance motors with two different configurations is designed by RMxprt. RMxprt uses a combination of analytical and magnetic circuit equations to predict the performance of this motor problem. RMxprt assumes the switched reluctance motor operates with shaft position feedback to synchronize the commutation of the phase currents with precise rotor position. Two modes of operations are supported: the single pulse operation, and the chopping current strategy. In the single pulse operation, each phase is energized at the turn-on angle and switched off at the turn-off angle. The difference between the turn-off and the turn-on angle is called the dwell angle. The chopping current strategy is a hysteresis-type current regulator in which the power transistors are switched off and on according to whether the current is greater or less than a reference current. RMxprt supports only switched reluctance motors in which the number of stator poles is greater than the number of rotor poles. The number of phases in the stator winding is the number of stator poles divided by the smallest common denominator of the number of stator poles and the number of rotor poles. The lead angle, which is positive if the phase is triggered before the aligned position between the phase axis and the rotor pole, should be constant over the entire range of speed.

Design1: figure (1) shows the geometry used in this case (a 3-phase SRM with 4rotor poles and 6 stator poles):

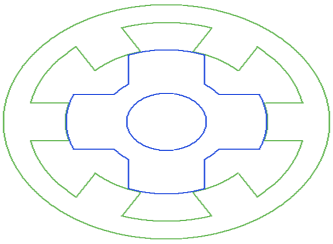

Fig. 1 SRM with 4rotor poles and 6 stator poles

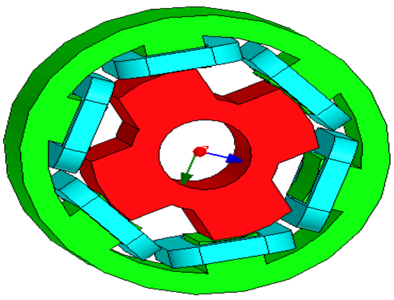

Fig. 2 three dimensional design of SRM

The motor main parameter is shown in Table I.

TABLE I
SPECIFICATIONS ADOPTED FOR THE SIMULATED MOTOR

NAME	RATING VALUES	UNIT
Rated Power	0.55	kW
Rated Voltage	220	V
Number of stator poles	6	-
Rated Speed	1500	rpm
Stacking factor of stator core	0.95	-
Number of rotor poles	4	-
Air gap	0.5	mm
Outer Diameter of stator	120	mm
Inner Diameter of stator	75	mm
Length of Rotor	65	mm
Inner Diameter of rotor	30	mm

After designing motor with this type of configuration and simulating motor in full-load condition flowing results is obtained.

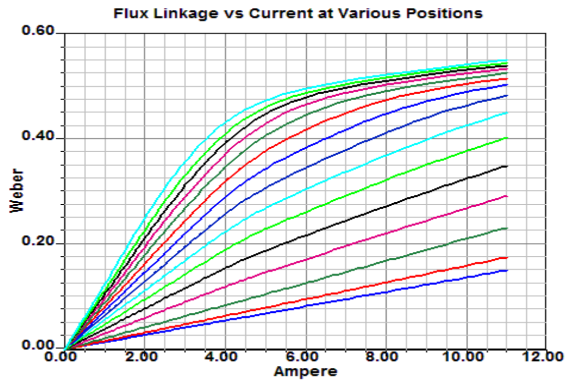

Fig. 2 Flux linkage versus current at various positions

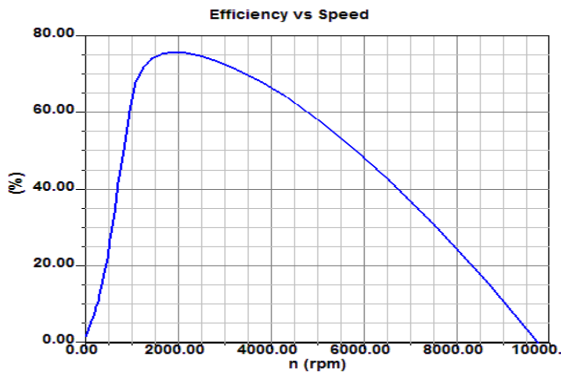

Fig. 3 efficiency versus speed

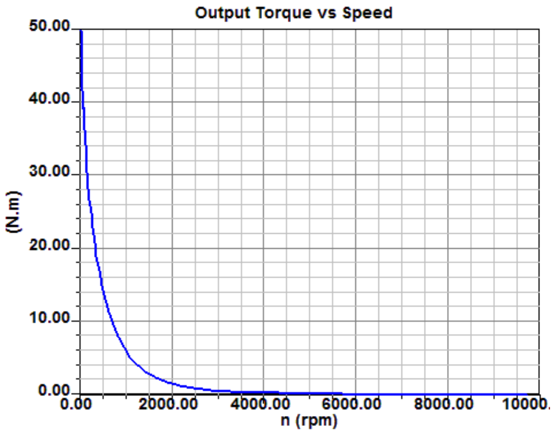

Fig. 4 torque versus speed

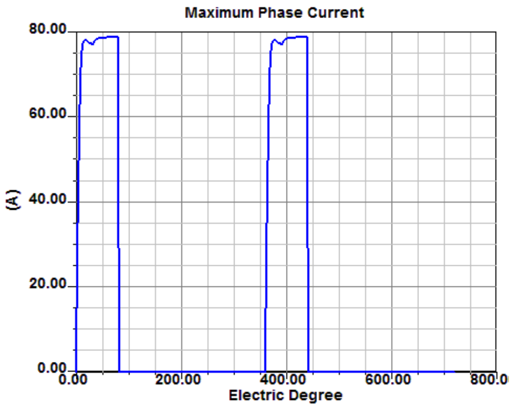

Fig. 5 phase current versus electrical degree

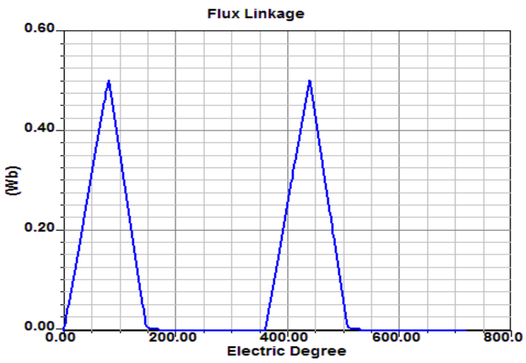

Fig. 6 Flux linkage versus electrical degree

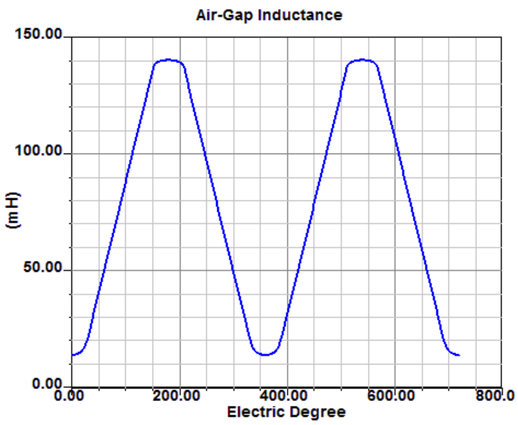

Fig. 7 air-gap inductance versus electrical degree

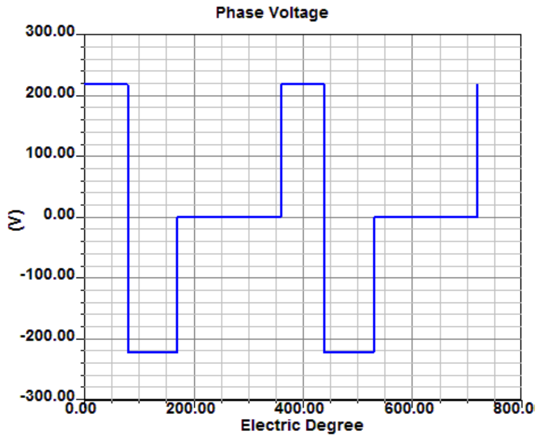

Fig. 8 phase voltage versus electrical degree

Figure 2 shows the magnetization characteristics of the low power SRM in 10 degree steps from the aligned position (0 degrees) to

Unaligned position (70 degrees).It is seen that in this design flux linkage reaches to 0.5 Weber, and efficiency reaches to 77.2%. This results shows that the peak torque is 0.9Nm for a phase current of 10.5A. Fig.5 shows the phase current. As we can see phase current reach to the highest value of 80 Amper. Fig.5 shows air-gap inductance reaches to the highest value of 150 mH.

Design2: the geometry used in this case is (a 4-phase SRM with 6rotor poles and 8 stator poles):

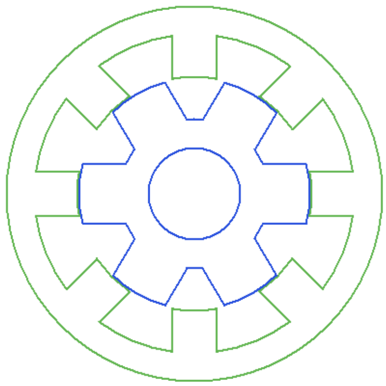

Fig. 9 SRM with 6rotor poles and 8 stator poles

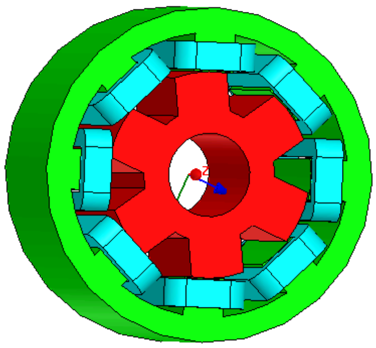

Fig. 10 Three dimensional design of SRM

The motor main parameter is shown in Table II.

TABLE II
SPECIFICATIONS ADOPTED FOR THE SIMULATED MOTOR

NAME	RATING VALUES	UNIT
Rated Power	0.55	kW
Rated Voltage	220	V
Number of stator Poles	8	-
Rated Speed	1500	rpm
Stacking factor of stator core	0.95	-
Number of rotor Poles	6	-
Air gap	0.5	mm
Outer Diameter of stator	120	mm
Inner Diameter of stator	75	mm
Length of Rotor	65	mm
Inner Diameter of rotor	30	mm

After designing motor with this type of configuration and simulating motor in full-load condition flowing results is obtained.

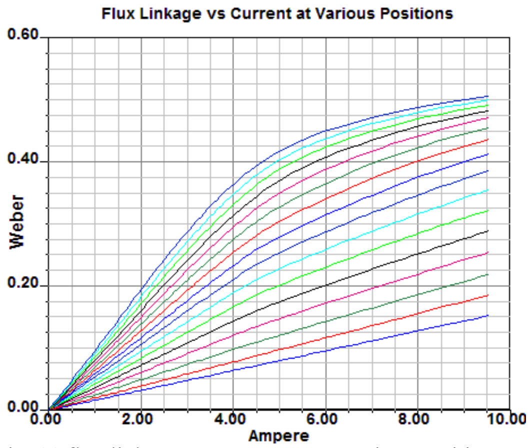

Fig. 11 flux linkage versus current at various positions

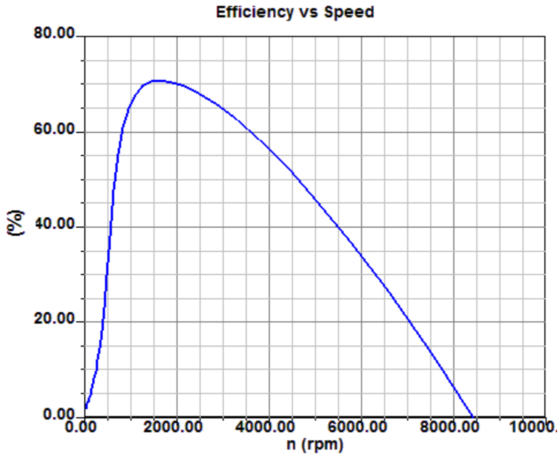

Fig. 12 efficiency versus speed

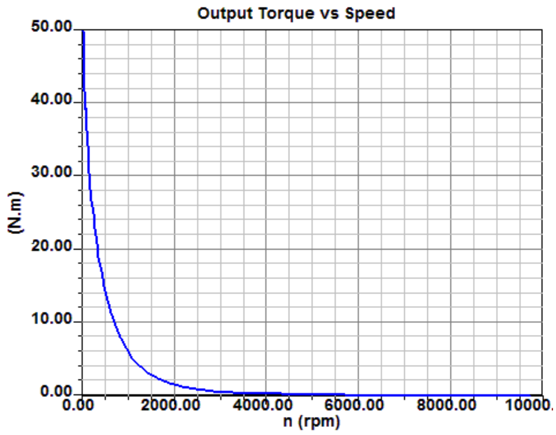

Fig. 13 torque versus speed

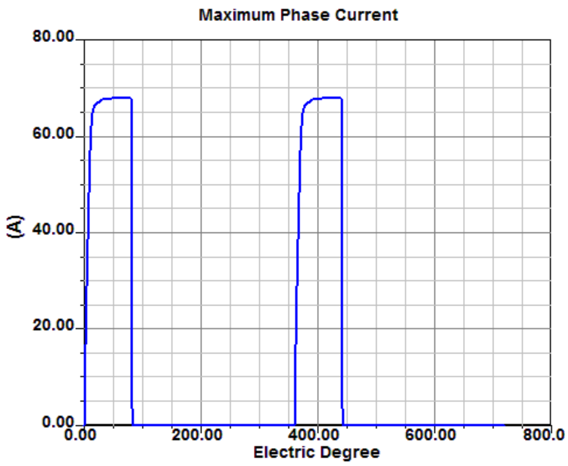

Fig. 14 phase current versus electrical degree

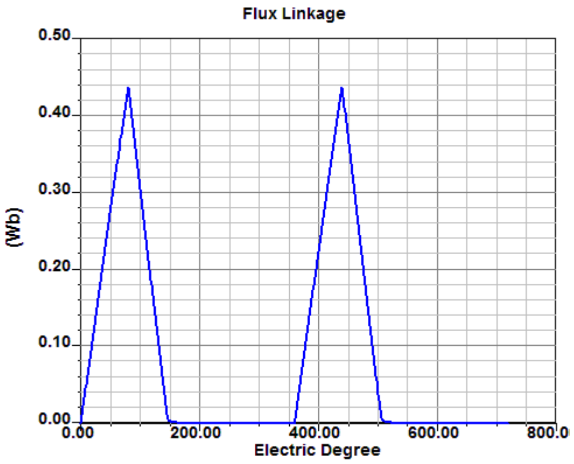

Fig. 15 Flux linkage versus electrical degree

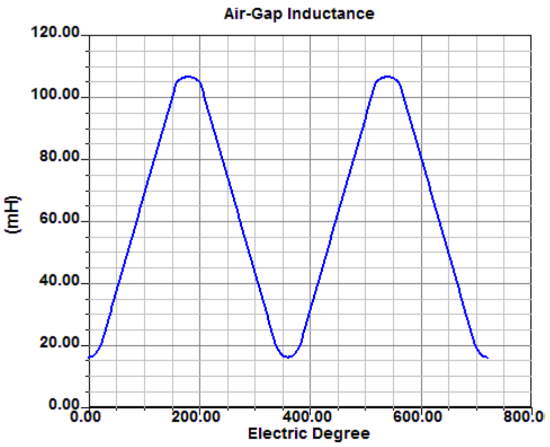

Fig. 16 air-gap inductance versus electrical degree

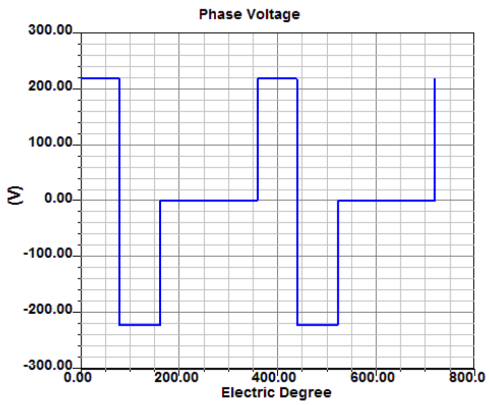

Fig. 17 phase voltage versus electrical degree

Figure 11 shows the magnetization characteristics of the low power SRM in 10 degree steps from the aligned position (0 degrees) to Unaligned position (70 degrees).It is seen that in this design flux linkage reaches to 0.41 Weber, and efficiency reaches to 70.2%. This results shows that the peak torque is 0.9Nm for a phase current of 10.5A. Fig.14 shows the phase current. As we can see phase current reach to the highest value of 67 Amper. Fig.16 shows air-gap inductance reaches to the highest value of 105 mH.

IV. Simulation and Results

For the first design values of the total loss, speed, and efficiency of the motor are shown in table II. It is seen that total loss is pretty large in this design as a result efficiency of motor is not very high.

TABLE III
THE RESULTS OF MOTOR ANALYSIS

NAME	VALUE	UNIT
Total Loss	218.879	W
Speed	1500	rpm
efficiency	71.514	%

For the second design values of the total loss, speed, and efficiency of the motor are shown in table III. It is seen that total loss is increased in this design as result efficiency is lower in contrast to previous design, but A four-phase SRM is selected due to the four-phase SRM producing less acoustic noise and torque ripple compared to a three-phase SRM [1][2].

TABLEIV
THE RESULTS OF MOTOR ANALYSIS

NAME	VALUE	UNIT
Total Loss	549.997	W
Speed	1500	rpm
efficiency	64. 678	%

The results shows that number of poles plays an important role in improving efficiency SRM motor and by changing the configuration of motor line current, total loss, and efficiency will be changed. Of course for more improvement of motor performance other parameters should be determined.

V.Conclusion

A complete model was developed with the objective of examining the behavior of the SRMs It can be concluded that pole number of rotor and stator play an important role in improving the efficiency of SRM motor. By changing the configuration of motor efficiency is changed. Hence, care should be taken in choosing the best structure for poles which yields maximum efficiency. It concluded from simulations that the largest flux density in the air gap and the smallest loss is the result of 3 phases SRM.

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